are here included 365 species. Of these 15 species are gymnosperms; 10, palms; 23, oaks; with 43 species of *Crataegus*.

These three books are published by the author.

SHORT NOTES

A NEW edition of the "Guide to the Spring Flowers of Minnesota" (by Clements, Rosendahl and Butters) has just appeared, so broadened and extended as to include the plants that ordinarily blossom by the middle of June. Small but helpful figures of about 160 genera are now given in the text. The plan of these "Guides," of which half a dozen have been published, is to be highly commended.

ANNOUNCEMENT is made of the early appearance of a book on "Rocky Mountain Flowers," by F. E. and E. S. Clements. It is to be "an illustrated guide for plant-lovers and plant users" and is to contain twenty-five colored plates, and about as many uncolored. An examination of some of the colored plates indicates that they will be highly artistic as well as botanically accurate. The volume is bound to be one that will appeal strongly to those who "summer" in the Rocky Mountains.

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SPECIAL ARTICLES

THE APPLICABILITY OF THE PHOTOCHEMICAL ENERGY-LAW TO LIGHT REACTIONS IN ANIMALS

IT has been pointed out by Loeb that tropistic light reactions in animals should follow the law of Bunsen and Roscoe. This law states that in a light reaction the effect is proportional to the simple product of intensity and time. It was first proved to be true for the formation of hydrochloric acid from chlorine and hydrogen and for the blackening of silver chloride under the influence of light. Later it was found to apply to the phototropic curvature (Fröschel, Blaauw) of plants, as well as to the human eye, though within rather narrow limits (Bloch, Charpentier). For light reactions in animals it has frequently been stated that they do not follow this simple law. A large number of forms seem to react to changes of intensity only, the effect in this case being proportional to the amount of change per unit of time. This is particularly true of the stimulating and inhibitory reflexes of the locomotor apparatus, as shown by a large number of investigators.

It occurred to me that it might be possible to get proof for the applicability of the energy-law by using a reaction which did not involve the locomotor organs. The eye movements of *Daphnia* seemed to afford a suitable object for the study of this question. These movements were first observed by Radl and his observations were confirmed and extended by myself some years later. The spherical eyeball containing a number of radially arranged ocelli is capable of rotation and held in position by several thin muscles inserted at its periphery. The eye shows a definite normal position with regard to light, a certain axis of the sphere having to be placed in such a direction that the ocelli on all sides of this axis get an equal amount of illumination. The muscles keep the eye in this position and one can cause rotating movements of the eyeball, by shifting the position either of the source of light or of the animal. The eye will always maintain its fixed position to the source of light, no matter whether the body of the animal follows the eye or not. An unequal state of tension of the eye muscles seems to cause locomotor movements, which tend to restore the normal relative position of eye and body. By fixing the animal on a slide it can be prevented from moving and the eye movements may be observed at leisure. Instead of shifting the position of the light the eye can be placed in a position of equilibrium between two sources of light and eye movements can be caused by increasing or decreasing the intensity of either of them. This shows these movements to be a function of the intensity of illumination.

In order to test the energy law, it is necessary to combine different light intensities with different times of exposure. If the product of time and intensity, *i. e.*, the amount of radiant energy brought to bear on the eye, is the same, the eye will always give the same

reaction. To this end I proceeded in the following manner. The animal was fixed in a definite position on the stage of a microscope, illuminated from below by a weak electric light of constant intensity. The microscope stood in a blackened dark-room. Through a hole in the wall of the room the light of an 80 candle-power Tungsten lamp fastened outside could enter. The light was made diffuse by a sheet of oiled paper fixed across the opening. The hole was 55 mm. in diameter and was closed by a piece of cardboard containing two diaphragms of varying sizes, side by side. A shutter with a spring motion could alternately close either the one or the other opening. I could thus make an instantaneous change from a stronger to a weaker light, and *vice versa,* by using diaphragms of different sizes and moving the shutter to and fro. One diaphragm was maintained at constant size (25 mm. diameter) and a sector wheel or episcotister, driven by a small electromotor, could be rotated before it. The light passing this diaphragm had an intensity of 0.9 c.p. The distance between the animal and the diaphragm was about 60 cm. Obviously, if two diaphragms were used whose areas were as 1:10 and a sector wheel with 1/10 of the periphery cut out were rotated before the larger one, so as to let light pass during 1/10 of a revolution, then equal amounts of radiant energy would reach the eye of the animal through either diaphragm.

The microscope was placed in such a position that the light from the diaphragms could fall on the stage from the side. If the smaller diaphragm was opened, the eye of the *Daphnia* took up a position, defined by the ratio of intensities of the light coming from the weak lamp below and from the diaphragm above. Changing from the smaller to the larger diaphragm would cause a change in the position of the eye. By varying the sizes of the diaphragms I found that a noticeable reaction was obtained upon changing from one diaphragm to the other, even when the difference between their areas was as small as 10 per cent. Change between diaphragms of equal size, however, did not produce a reaction.

Using the diaphragm ratios 5:10, 2.5:10 and 1:10 I invariably found that upon using a sector wheel cutting down the time of exposure for the larger diaphragm so as to make the amount of energy equal to the smaller one, I obtained *no reaction* on change from one to the other. If I used sector wheels giving too long or too short exposures, a reaction was noticed, where the error exceeded 10 per cent. *These observations prove that for the eye movements of Daphnia the energy law holds within the limits of accuracy characteristic of the reaction.* The speed of the sector wheel in these experiments was about 1/30 of a second for one revolution. If slower speeds were used, marked deviations from the law began to appear, the intermittent having a weaker effect than the constant light. In some cases I got a marked reaction of the eye on change from constant to intermittent light of equal energy when the speed of the sector wheel was about 1/10 of a second per revolution. The deviation becomes more marked, the slower the speed. The explanation for this phenomenon will be dwelt upon in a subsequent paper.

Strictly speaking, the law proved by my experiments is not the Bunsen-Roscoe law, but the law discovered more than twenty years earlier (1834) by Talbot, which states that the effect of intermittent light equals that of a constant light, if it emits the same amount of energy through a given period. In our case it means practically the same as Bunsen-Roscoe's law, each revolution of the sector wheel constituting one period, in which there is a given relation between intensity and duration of the light flash and a definite time for reaction. The variously arranged sector wheels provide the possibility of testing different ratios. The constant light coming from the smaller diaphragm is used in such a way as to serve as a measure or standard of comparison and circumvent the necessity of determining a threshold of stimulation.

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